Research on High Power Railguns at the Naval Research Laboratory

R.A. Meger, J. Neri, R.J. Allen, R.B. Hoffman, C.N. Boyer [a], B.M. Huhman [a]
Plasma Physics Division

K.P. Cooper, H. Jones, J. Sprague, S. Qadri
Materials Science and Technology Division

I.L. Singer
Chemistry Division

Naval Research Laboratory, Washington, DC 20375-5346

Abstract— The Naval Research Laboratory (NRL) has initiated a program focusing on railgun bore materials science. The objective of the program is to study the conditions in a high power railgun barrel during launch. An 11-MJ prime energy, 6-m long, 5-cm bore diameter railgun is being built for testing. This laboratory launcher will be used to study sliding contacts under the extreme current, temperature, and pressure conditions found in a high power railgun. Real time diagnostics coupled with extensive post-shot materials analysis will be used to understand railgun operation. Results will be compared with other high power railguns.

I. Introduction

The Naval Research Laboratory has initiated a program to study the materials science aspects of a high power railgun launch. To do so a new Materials Testing Facility (MTF) has been set up. The laboratory houses a new 11-MJ, 6-m railgun designed for diagnostic access and experimental flexibility. The design parameters for the new railgun are discussed below. Experiments are to begin by spring 2006 and the railgun should be fully operational by October, 2006. This paper will lay out the design of the new laboratory and railgun. Laboratory status and first results will be presented at the Symposium.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Research on High Power Railguns at the Naval Research Laboratory**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,Washington,DC,20375-5346**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at the 13th International Symposium on Electromagnetic Launch Technology (EML), Held May 22 - 25, 2006 in Potsdam, Brandenburg, Germany Copyright 2006 IEEE. Published in the Proceedings. http://emlsymposium.org/archive.html

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

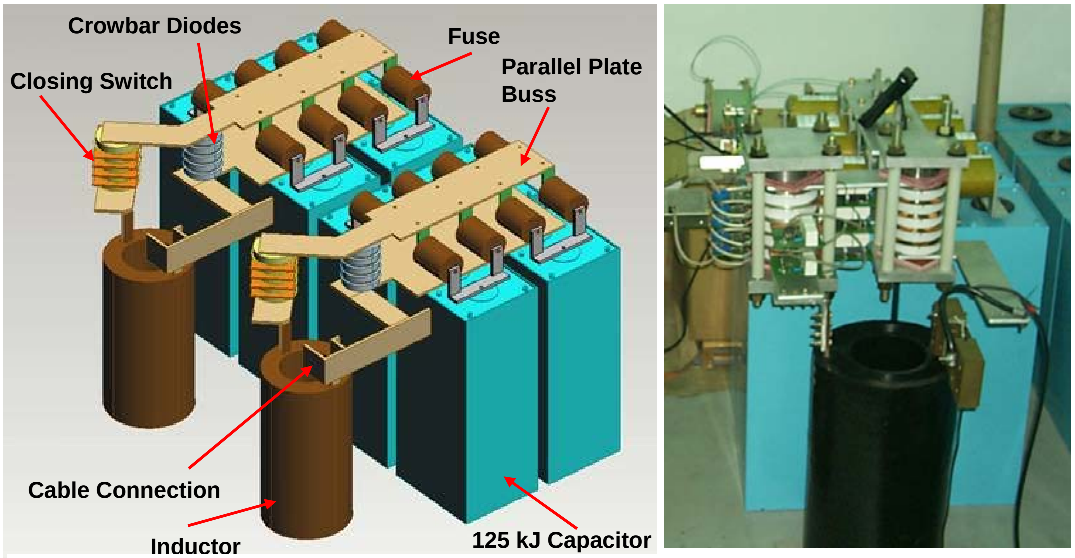

Fig. 1. Drawing of two 0.5 MJ modules. Four 11-kV caps connected in parallel are switched using stacked thyristors and crowbared using stacked diodes. An 80 μH inductor is connected in series with the module output. The picture at right shows testing of a single module. Waveforms agree with predictions.

II. ENERGY STORAGE BANK:

The capacitive energy store shown in Fig. 1 is designed to drive in excess of 1 MA through a 6-m long railgun. The bank is comprised of 22, 0.5-MJ modules. Each 500-kJ module contains four 2040 μF, 11 kV capacitors, each with series fuses; a set of stacked ABB thyristors and crowbar diodes; and a series 80-μH cylindrical inductor.

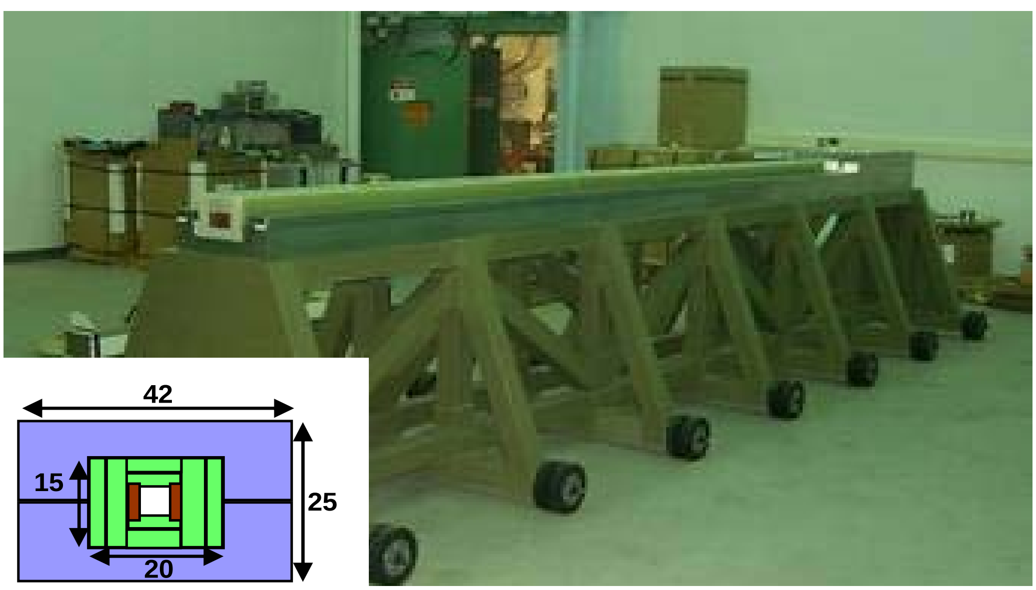

Fig. 2. Picture of the NRL Railgun with a schematic (inset) of the railgun cross section.

Each module is designed to provide 100-kA peak current pulse. The 22 modules, isolated by the energy storage inductors, can be fired independently to provide waveform control. The bank modules are connected via coaxial cable to a current manifold at the breech end of the railgun. A single 0.5 MJ module of the system has been tested and the waveforms were found to agree with the code predictions.

III. RAILGUN DESIGN:

The design criteria for the NRL railgun were two-fold. First the gun containment had to be able to withstand up to 2 MA current driven through a 5 cm square bore, 6-m long railgun. Second the containment had to allow significant diagnostic access and rapid assembly/disassembly to facilitate experimental tests. The containment design is shown in figure 2. The outer containment is comprised of stainless steel, C-shaped shells bolted together. Stainless steel wedges (not shown) are used to provide a controlled pre-load to the rails and to align the 1-m long containment sections. The 43 cm x 27 cm containment provides a 22 cm x 15 cm rectangular region to house the rails and insulators. Diagnostic access is available along the center of the containment and through the sides. A 5-7 cm bore, square, rectangular, or round bore rail and insulator set will be mounted inside of the containment using hard insulators or laminated metallic structures to fill the space between the rails and the containment walls. The C-shaped containments were designed to withstand the pressures generated by up to a 2 MA launch. The solid cross section was chosen over a laminated design to facilitate access and allow multiple sizes and shapes of rails and insulators to be tested. A 5-cm square bore configuration will have an inductance gradient of ≈0.4 μH/m including the return current component due to the containment. The solid walls decrease the inductance per unit length by ~15% over a non-conducting containment due to return currents generated in the structure. Figure 3 shows a finite element analysis calculation using the Finite Element Method Magnetics code [1] of the magnetic field structure for the NRL railgun. The calculation was done for a 1 MA current with a 10 kHz oscillatory waveform (simulates 25 us pulse risetime) with a stainless steel containment and copper rails. Peak field on axis was ≈85 kG. The confinement of the flux lines inside of the containment structure indicates that return currents flow in the steel

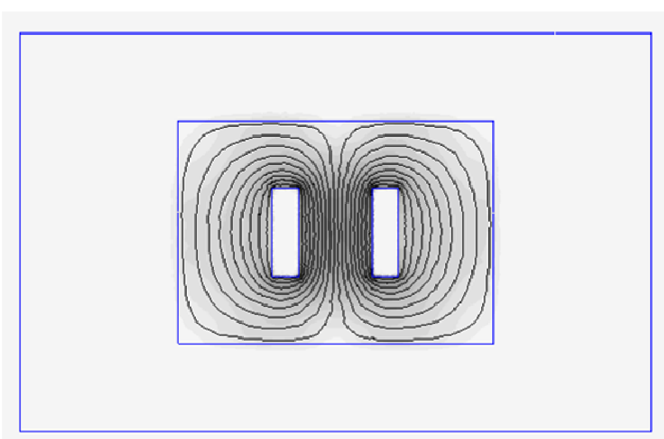

Fig. 3. FEA calculation of the magnetic field for the NRL Railgun. 1 MA current is driven in the 5-cm square bore railgun. Type 304 stainless steel containment used. Peak field on axis ≈85 kG for 1 MA rail current.

structure. The containment is configurable in 2, 4 or 6-m long increments. The gun itself is mounted on a reinforced plastic carriage shown in figure 2. The structure is designed to remove all metallic support structures from the vicinity of the rails to maintain magnetic field symmetry. A 30-cm diameter, 3-6 m long vacuum tube is located downstream of the railgun muzzle which ends in a 1.5-m diameter target chamber. The transport line and target chamber will be kept at a fraction of an atmosphere to suppress muzzle arc and to contain impact debris. The target chamber is located in a 45-cm thick concrete bunker to contain any impact debris should it escape the target chamber.

IV. MATERIALS TESTING FACILITY:

The railgun is contained in a 3,000 sq. ft. laboratory at the Naval Research Laboratory in Washington, DC. The lab houses the banks, railgun, and support facilities. A 48-channel digitizing system is available to record shot data. The railgun is operated by a computer system with real-time feedback to manage and prevent catastrophic failures. A dual beam flash x-ray system located in the transport section is available to image the projectile as it passes. Magnetic field, pressure, and temperature sensors will be used to monitor the launch along with optical imaging and spectral diagnostics in the bore and along the flight path. Post shot analysis of the rails and insulators will be performed at facilities located throughout the Naval Research Laboratory. These diagnostics include surface profilometry, high resolution optical microscopy, scanning electron microscope imagery, energy dispersive spectroscopy, x-ray fluorescence, grazing incidence x-ray diffraction, bulk and surface hardness measurements, and others. These diagnostics will provide an abundance of information about the bore materials [2], [3]. Additional facilities for investigating static contacts

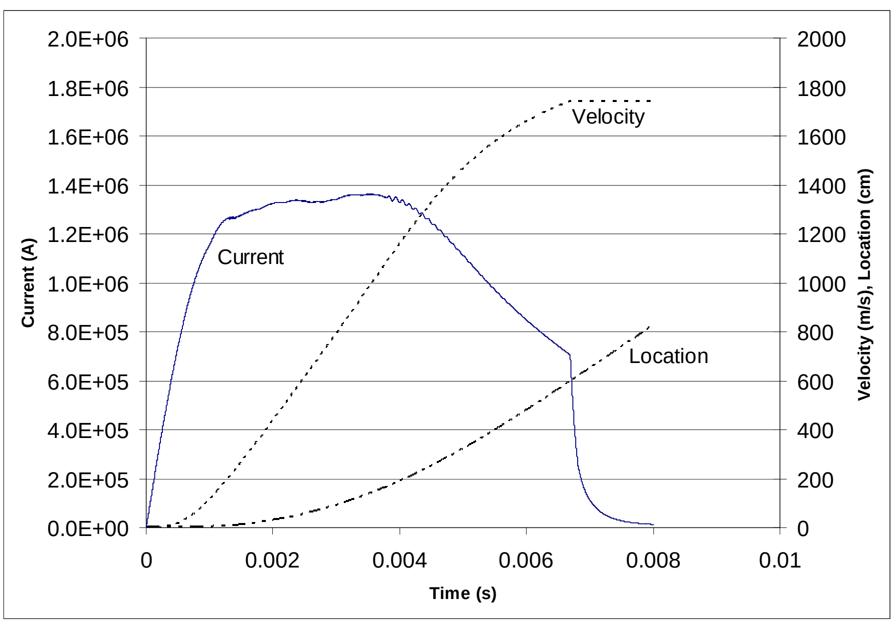

Fig. 4. Simulation of the current, velocity, and position for a 1 kG projectile accelerated by 11 MJs of capacitive energy store. Simulation utilizes expected parameters for NRL railgun.

[4], low power railgun launch, and materials properties are located in the lab as well.

V. NRL RAILGUN LAUNCH SIMULATION:

Figure 4 shows a simulation of a launch on the NRL railgun presently being assembled. The code couples the 22, 0.5 MJ bank modules pulsed at arbitrary delay times to a projectile assuming an idealized coupling through the barrel inductance gradient. It provides a best case prediction for launcher performance and has successfully predicted launch parameters for other railguns. A 1 kg launch package is chosen for this simulation with the calculated 0.4 μH/m inductance gradient. 13 of the 22 banks charged to a full 11 kV were fired at t=0 and the remaining 9 bank modules were spaced out over the succeeding 1 ms to generate the current waveform shown in the figure. The bank current peaked at 1.35 MA when the projectile was at the 2-m location. The current in the system dropped thereafter as energy continued to be coupled into the projectile kinetic energy. The current dropped to 720 kA at the muzzle exit where a resistive muzzle arc suppressor was used to absorb the remaining inductive energy. In this test case the 1 kg projectile leaves the barrel at 1.7 km/s. The code shows that control of the waveform, firing sequence, and projectile mass allows testing under a range of currents, velocities, and acceleration profiles. The open geometry of the barrel will allow installation of different size and geometry rails and insulators. The objective of the launcher is to study barrel materials issues under high stress conditions. The system offers a versatile tool for these studies.

VI. SUMMARY AND CONCLUSIONS:

The Naval Research Laboratory is poised to begin a focused program on railgun materials. Real time and post-shot analysis will provide information about the rail-armature interface. The information hopefully will lead to understanding as well as scaling relations for future railguns.

Acknowledgment

This work was supported by the US Office of Naval Research.

References

[a] L3-Titan Corp., Reston, VA 20191

[1] Finite Element Method Magnetics (FEMM) code, available from http:://femm.foster-miller.com.

[2] R.A. Meger, K. Cooper, H. Jones, J. Neri, S. Qadri, I. L. Singer, J. Sprague, and K. J. Wahl, “Analysis of Rail Surfaces From a Multi-shot Railgun,” IEEE Trans. on Magnetics, vol. 41(1), pp. 211-213, January 2005.

[3] K. P. Cooper, H. N. Jones, R. A. Meger, “Metallurgical Analysis of Railgun Material,” these proceedings.

[4] H. N. Jones, J. M. Neri, C. N. Boyer, K. P. Cooper, R. A. Meger, « Pulsed Current Static Contact Experiment,” these proceedings.